# 7.—The environment of deposition of the Wooramel Group (Lower Permian), Lyons River area, Carnarvon Basin, Western Australia

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### Abstract

Studies of the Wooramel Group, comprising the Moogooloo Sandstone and the Billidee Formation, in the Lyons River area indicate that the environment of deposition of the Moogooloo Sandstone was a temperate to cold, shallow marine environment, perhaps deltaic. Sedimentation was rapid, with abundant reworking of sediments and steady, fairly strong currents, possibly tidal in part. Conditions changed in late Moogooloo time with the development of euxinic conditions with periodic influxes of sand.

The overlying Billidee Formation is believed to have been deposited in shallow water near-shore conditions, with occasional subaerial exposure. Fairly strong currents flowed to the north during deposition of the sandstones. Stagnant anaerobic conditions prevailed during the deposition of the carbonaceous shales. There was rapid alteration between aerobic and anaerobic conditions. The deposition of the *Edmondia* band was marked by a minor marine transgression.

Modern sedimentary analogues are discussed.


## Introduction

This paper presents the results of a study of the environment of deposition of the Wooramel Group (Lower Permian) in the eastern Carnarvon Basin. In the area studied (Fig. 1) the Wooramel Group comprises the Moogooloo Sandstone conformably overlain by the Billidee Formation.

No previous work has been published dealing with the depositional environments of the Moogooloo Sandstone or the Billidee Formation, except for the brief comments made by Condon (1954, 1967).

The base of the Wooramel Group is at the sharp change in lithology from fossiliferous calcareous sediments (Callytharra Formation) to arenaceous sediments largely devoid of fossils. The top is at the change in lithology, commonly gradational, from arenaceous sediments to dominant lutite sediments.

In the area mapped, the Wooramel Group comprises the conformable sequence of the Moogooloo Sandstone and the Billidee Formation. The Moogooloo Sandstone, the lower unit, overlies the Callytharra Formation, either conformably or disconformably. The Billidee Formation is overlain unconformably by the Coyrie Formation (Byro Group). The age of the Wooramel Group is Artinskian because of its position between the Callytharra Formation, of late Sakmarian-early Artinskian age, and the Artinskian, Byro Group.

## Moogooloo Sandstone

In the Lyons River area, the Moogooloo Sandstone is the basal formation of the Wooramel Group.

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The Moogooloo Sandstone consists of red, brown and white, fine- to coarse-grained orthoquartzite, subordinate subarkose (feldspathic sandstone) and orthoconglomerate. Minor interbedded silty shale is present in the upper part of the formation. The petrology has been described by McGann (1974).

In the Moogooloo Sandstone, sedimentary structures give the best clues to the environment of deposition.

### *Cross stratification*

Cross stratification is common in the Moogooloo Sandstone with sets ranging in height from 2 cm to 3 m. A subdivision into small-, medium- and large-scale cross stratification (Conybeare and Crook 1968) is used.

*Medium-scale.*—Medium-scale cross stratification, which is the most common type of cross stratification in the formation, ranges from 60 mm to 2 m. The average height of a set is about 33 cm. A coset comprises from one to four individual sets. The maximum dip is 30°. The medium-scale cross stratification is of Allen's (1963) Omikron class, formed, he believes, by migration of trains of large-scale asymmetric ripple marks with essentially straight crests. This type of ripple is found in channels or in the open sea at depths many times the wave-ripple height, but still in shallow water.

*Large-scale.*—Trough cross stratification is the most common type of large-scale cross bedding. The large-scale cross beds are isolated sets bounded above and below by "massive" fine- to medium-grained orthoquartzite. The maximum dip is 32° and the average dip is 16°.

The large-scale cross stratification is of Theta type (Allen 1963), which is believed to be scour and fill structures formed in a shallow water environment.

*Small-scale.*—Small-scale (less than 6 cm) cross stratification, although not common in the Moogooloo Sandstone, is present within small, essentially symmetrical ripples of amplitude less than 3 cm. The cross stratification is tabular, solitary and lithologically homogeneous. The small-scale cross stratification is probably Lambda type (Allen 1963), formed by a migration of small-scale straight-crested ripples in a shallow water environment.

Small-scale ripple-drift cross lamination is present in one specimen. Walker (1963) suggests that this type of cross lamination is produced by a steady current and abundant sediment supply.

The azimuth of 152 foresets was measured, one to approximately every 500 m$^2$. The vector mean is N 3° E, with a high variance of 8 440 (standard

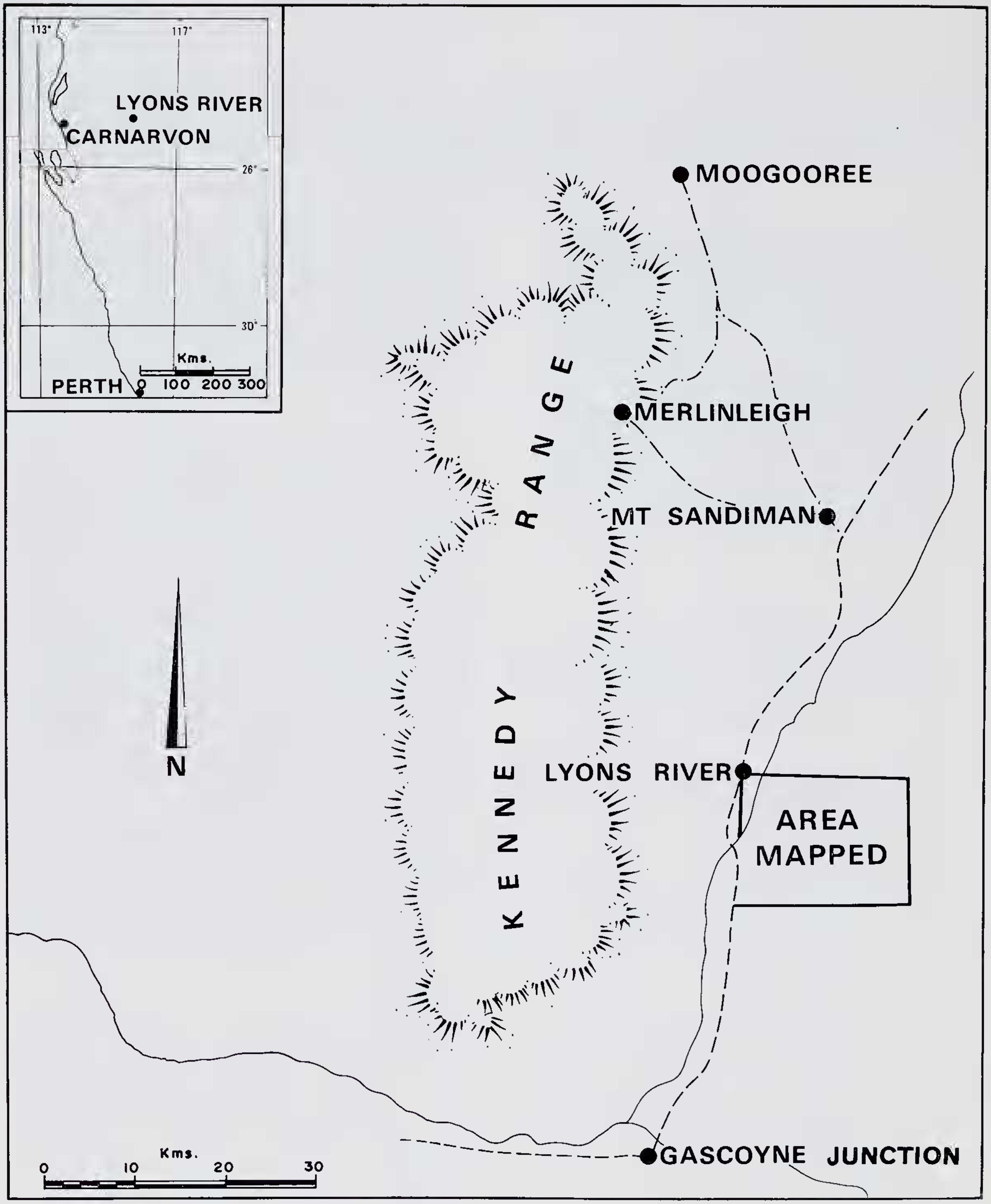


Figure 1.—Locality plan.

deviation of 92°). The results are summarized in Fig. 2. The dominant current flow is towards the north with a subordinate flow towards the south.

### *Ripple marks*

Slightly asymmetric ripples are the only type recognized in the area studied. The ripples are of an amplitude ranging from 1 cm to 5 cm with a wave length between 10 cm and 1 m.

Slightly asymmetric ripples suggest an environment of deposition above wave base in a shallow, relatively open sea.

### *Slump structures*

Two distinct types of slumping are observed in the Moogooloo Sandstone.

*Slumping within cross stratified sets.*—The foresets of some medium-scale cross stratified sets are distorted. This distortion ranges from minor folds on the foresets to folds where the foresets are parallel to the lower bounding surface. The upper surface of the set is everywhere erosional, indicating that the deformation was penecontemporaneous with deposition. The deformed sets are confined to particular horizons. Jones (1962) presents five possible causes of this type of deformation, the most acceptable in the present instances being surface thrusting generated by currents while the sand is still in a plastic state.

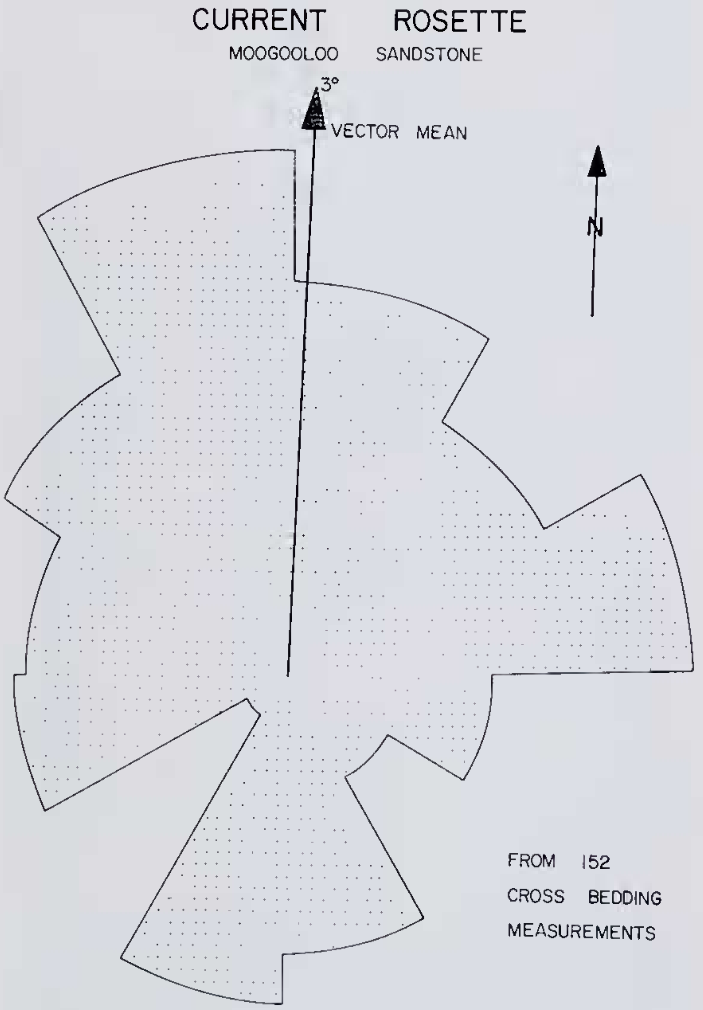


Figure 2.—Current rosette, Moogooloo Sandstone.

*"Normal" slumping.*—"Normal" slumping is present in plane bedded fine- to medium-grained sandstones as minor folds which do not persist vertically, and is often in the same general horizon as the slumping within cross-stratified sets.

### *Shale clasts*

Two types of shale clast are present, both restricted to stratigraphically variable beds which persist for up to 300 m. Both are present only in fine- to medium-grained orthoquartzites

The most common type of shale clast consists of scattered plates of grey fine-silt to clay-sized material roughly parallel to the bedding. The plates are about 2.5 cm in diameter and less than 3 mm thick.

A second type consists of tear or ellipse shaped silty-clay clasts about 11 cm long and 4 cm high.

### *Fossils*

Indeterminate brachiopods, bryozoans and bivalves have been found sporadically in the formation throughout the basin. Despite an active search, however, only fossil wood was found in the area mapped.

*Trace Fossils.*—Tracks are present only in the upper part of the Moogooloo Sandstone, where they are extremely common. The tracks are confined to particular horizons. They consist of smooth, slender, circular tubes about 1 cm in diameter. In places, the tubes, which are essentially straight, interpenetrate, but they do not branch. At least one species of *Palaeophycus* Hall 1847 is represented. The affected beds are extensively ferruginized.

Osgood (1970) believes that *Palaeophycus* tracks were produced by worms and the lack of distinct pattern indicates that they were predators, probably in a shallow water environment.

### *Environment of deposition*

From the data accumulated in this investigation it is possible to construct an environment of deposition for the Moogooloo Sandstone.

Cross stratification types and ripple marks suggest shallow waters with the depositional surface above wave base. Shale clasts indicate subaerial exposure or near-shore marine conditions (Conybeare and Crook 1968, p. 20).

Palaeocurrent data indicate that the palaeoslope was towards the north, the high variance indicating that the slope was of low angle. Tidal currents could be the main factor controlling the subordinate south-trending current. Sunborg (1956, cited by Lauff 1967) has indicated that currents of approximately 0.3 m/sec. would be necessary to move the average sized grain (0.3 mm). Obviously current strengths were greater at the time of deposition of conglomerates and coarse-grained sands. The high degree of winnowing of the sands suggests that the current was not intermittent, but persisted over long periods.

Mineralogical and textural maturity, as indicated by the low proportion of labile minerals, good rounding and sorting, suggests that considerable reworking has taken place (McGann

1974). A high-grade metamorphic or granitic provenance is indicated.

The virtual absence of fossils is probably due to a combination of continual reworking, attrition and abrasion, leading to almost complete breakdown of fossil grains. This reworking was probably combined with rapid sedimentation which would have two effects, the first being to produce an environment unfavourable to all but a few fossil groups. The second effect would be to "dilute" skeletal remains with abundant terrigenous clastic material. The overall result is that fossils remain only in isolated patches, probably representing more sheltered parts of the environment. The sparse fossils that are present, including *Palaeophycus* sp., indicate a shallow marine environment. The abundance of fossil wood indicates proximity to land and is often diagnostic of deltaic conditions (Shepard 1964).

The climate was temperate to cold, as inferred from palynological evidence obtained from a shaly unit just above the Moogooloo-Billidee contact. There is no evidence to suggest that climatic conditions changed greatly between Callytharra and Moogooloo time. The climate in Callytharra time is interpreted as cool (Teichert 1941).

The environment of deposition changed somewhat in late Moogooloo time with the deposition of gypseous carbonaceous silty shale interbedded with coarse-grained orthoquartzite containing *Palaeophycus* sp. This genus is indicative of shallow water conditions, and thus the interbedded carbonaceous shale was also deposited in shallow water. A stagnant environment was responsible for low oxidation potentials, which resulted in the high proportion of carbonaceous matter in the shale. Influxes of coarse-grained sand, deposited in aerobic conditions (as indicated by *Palaeophycus* sp.) periodically interrupted the euxinic environment.

When considering the environment of deposition of the Moogooloo Sandstone, the large outcrop area with uniform gross lithology (Teichert 1952) must be taken into account, and only a sedimentary model that is laterally extensive can be considered analgous to the conditions in Moogooloo time.

In summary, the available evidence indicates a shallow nearshore marine environment, perhaps deltaic, with rapid sedimentation, abundant reworking and steady, fairly strong currents, possibly tidal in part. Conditions changed in late Moogooloo time with the development of euxinic conditions with periodic influxes of sand.

Comparison of the Moogooloo Sandstone with recent analogues is handicapped by the lack of detailed work done on modern terrigenous sediments. Fisher *et al.* (1969) briefly describe the Gulf of Papua delta, naming it as the type example of a destructive, tide-dominated delta. The facies present in this model are analogous with the facies present in the Moogooloo Sandstone. The bulk of the formation—the orthoquartzite suite—is thought to represent the tidal sand-bar facies, the textural and mineralogical maturity, together with the lack of fossils and the sedimentary structures all being produced in a predominantly marine environment with extensive reworking by tidal currents, and to a lesser extent, by waves. The conglomerate in the Moogooloo Sandstone may represent tidal channel facies, the channels running between sand bars. A shaly prodelta facies is not seen in the formation.

In late Moogooloo time, euxinic conditions gradually became prevalent, probably by the development of barrier bars with a complementary lagoonal-estuarine system. Periodic influxes of coarse sand, perhaps land derived, were introduced into the euxinic environment. The change to shallow water conditions could have been produced by a minor regression or, more likely, by normal building up of the delta platform as sediment accumulated.

Condon (1954) considered that the Moogooloo Sandstone was the product of slow deposition, caused by a major transgression on to a stable shelf. Major transgression may not have been necessary, however, as the underlying Callytharra Formation was laid down in a deep shelf environment, and the Moogooloo Sandstone represents a delta prograding on to this shelf. Thus, no major change in sea level is necessary to explain the Callytharra and Moogooloo facies.

### Billidee Formation

The Billidee Formation consists of orthoquartzite and calcite-cemented sandstone (some fossiliferous) and gypseous, carbonaceous silty shale.

Only one unit in the Lyons River area persists throughout the area mapped. This unit is an easily identified calcite-cemented sandstone with locally abundant bivalves. The unit is named the *Edmondia* band, after the large bivalve which is characteristically present.

As with the Moogooloo Sandstone, in the Billidee Formation, sedimentary structures are useful in reconstructing the environment of deposition.

Cross stratification is common in the sandstone units, but poor outcrop makes detailed examination impossible. Both large- and small-scale cross stratifications are present, large-scale being by far the most abundant.

The average height of large-scale cross stratification is about 60 cm and the maximum dip is 30° (average for 42 readings is 19°). The only type observed took the form of single troughs. Small-scale cross stratification is present as cosets containing up to four sets, the height of each set being about 3 cm. The lower bounding surface is erosional, and the foresets are probably trough shaped. The small-scale cross stratification is the Nu type of Allen (1963), probably formed from the migration of trains of linguoid small-scale asymmetrical ripples in shallow water.

The azimuth of 96 foresets was measured, one to approximately every 200 $m^2$. The vector mean is N 16° W with a variance of 3 650 (standard deviation of 59.7°). The results are summarized in Fig. 3. The dominant current direction was towards the north.

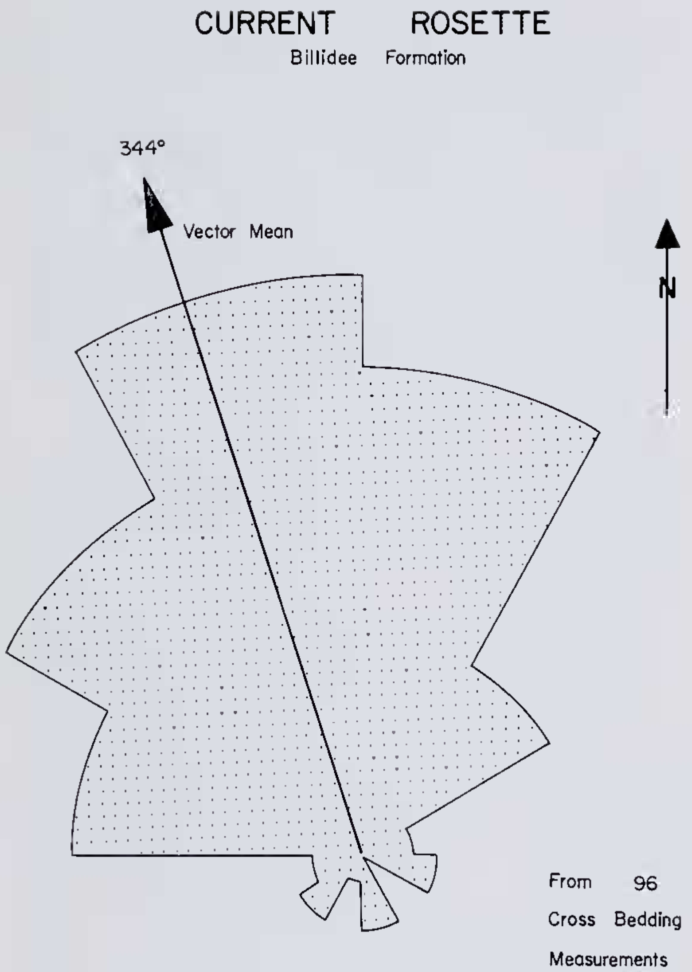

Figure 3.—Current rosette, Billidee Formation.

Rare symmetric, small-scale ripples were observed in fine-grained orthoquartzite. Shale clasts are abundant in the Billidee Formation, occurring in beds traceable for up to 500 metres. The clasts are essentially planar grey mudstone plates about 3 cm in diameter and about 3 mm thick, and are oriented parallel to the bedding.

Vertical ferruginized tubes are common in the *Edmondia* band. The presence of a central, more ferruginized, column suggests that they are root casts and not burrows. One specimen in the *Edmondia* band shows well-developed root casts in a clayey lime mud. The casts are about 1 cm in diameter and are infilled with detrital grains supported by ferroan calcite cement. The area surrounding the cast is extensively ferruginized, probably resulting from oxidation of organic matter. The root casts are cut by a number of collophane "tabulae", which penetrate the carbonate mud, where they bifurcate. The tabular form of the veins indicates that they are probably dessication cracks, infilled with collophane. A ferruginized clay horizon, about 4 mm thick, is present. It is believed to represent a fossil soil horizon. The carbonate mud contains many sparry ferroan calcite patches up to 1 mm long and 0.02 mm wide. These patches are thought to represent root hairs that have rotted out, the voids being infilled with sparry ferroan calcite. Marine fossils are closely associated with the root casts.

*Fossils*

The fossils previously reported from the Billidee Formation are:

Bivalvia:
- *Nuculopsis (Nuculanella)* sp.
- *Nuculana* sp.
- *Oriocrassatella* sp.
- *Aviculopecten* sp.
- *Schizodus* sp. cf. *S. kennedyensis* Dickins
- *Stutchburia* n. sp.

Gastropoda:
- *Mourlonia (Pseudobaylea?) n. sp.?*
- *Macrochilina* sp.
- *Warthia* sp.
- *Pleurotomaria* sp.
- Bellerophontid

Ammonoidea:
- *Propinacoceras* sp.
- *Neocrinites* sp.

Brachiopoda:
- *Neospirifer* sp.
- *Aulosteges* sp.
- *Strophalosia* sp.
- Chonetid
- Productid

Crinoidea:
- *Calceolispongia* sp.

An indeterminate bryozoan was also reported.

In the area mapped, fossils were found only in the *Edmondia* band (except for a highly calcreted bivalve lower in the formation). The fauna is impovished in species and in the number of individuals, and is dominated by bivalves.

Poorly preserved *Edmondia* sp. is common, as broken, disarticulated valves, distributed sporadically throughout the calcite-cemented sandstones. *Oriocrassatella* sp. is locally abundant, as disarticulated, and often broken, valves. Other bivalves present are *Schizodus* cf. *kennedyensis* and *?Nuculopsis* sp. The gastropods *Warthia* sp. and *Mourlonia* sp. are also present. Some phosphatic cylindrical fragments up to 6 cm long were collected, and tentatively identified as fragments of arthropods. One *Stenopora* sp. was seen in thin section. *Stenopora* sp. has not previously been reported from the Billidee Formation.

Silicified fossil wood (*?Araucaria)* is common, and is distributed randomly throughout the sandstone units of the formation.

*Palynology*.—A carbonaceous shale sample (University of Western Australia sample no. 65501) yielded a rich but not very diverse nor well-preserved assemblage dominated by *Sulcatisporites potoniei* (Lakhanpal, Sah and Dube). The other pollen grains are mainly disaccate, nonstriate or monosaccate. The forms present are:

- *Sulcatisporites potoniei* (Lakhanpal, Sah and Dube)
- *Leiotriletes directus* (Balme and Hennelly)
- *Protohaploxypinus limpidus* (Balme and Hennelly)
- *P.* sp. cf. *P. amplus* (Balme and Hennelly)
- *Platysaccus leschiki* Hart
- *Microbaculispora tentula* Tiwari
- *Acanthotriletes tereteangulatus* (Balme and Hennelly)
- *Limitisporites* sp.
- *Florinites eremus* (Balme and Hennelly)
- *Apiculatisporis* sp.
- *Cordaitina janakii* Potonie and Sah
- *Neoraistrickia ramosa* (Balme and Hennelly)
- *Veryhachium trispinosum* Deunff.

Balme (personal communication) states that this assemblage is typical of early Artinskian coal-bearing sediments from the Perth and Collie

Basins. It is identical with those from the Irwin River Coal Measures (northern Perth Basin) and the lower coals at Collie.

In the Carnarvon Basin, similar assemblages are seen in the Coyrie Formation and also the Keogh and One Gum Formations (formations of the Wooramel Group).

The assemblage is unlike the synchronous Poole Sandstone of the Canning Basin, which contains a diverse pteridophyte suite and a more varied gymnosperm pollen, leading Balme to believe that the Billidee Formation was probably deposited in a cooler climate than the Poole Sandstone.

Spores and pollen grains completely dominate microplankton, with only one specimen of *V. trispinosum* observed.

*Environment of deposition*

From a study of field relations, petrology, sedimentary structures, fauna and flora it is possible to assemble the following evidence concerning the environment of deposition of the Billidee Formation:

(a) Water Depth: The rapid horizontal and vertical variation in lithofacies indicates rapidly changing conditions during deposition. Such conditions would only be expected from a shallow water environment; deep water environments produce much more monotonous and laterally persistent lithofacies.

The dominance of spores over microplankton suggests nearshore, thus probably shallow water, conditions.

The association of probable root casts with dessication cracks suggests that shallow water plants, subaerially exposed at times, were present during deposition. Shale clasts also indicate subaerial exposure or nearshore conditions (Conybeare and Crook 1968).

The *Edmondia* band marks a change to slightly deeper water conditions, with the marine influence on sedimentation becoming more noticeable.

(b) Currents: Essentially unidirectional currents, towards the north, were responsible for the deposition of the cross stratified sands. Tidal currents were probably not significant. Current strengths were strong enough to transport and break bivalve valves, and are estimated at about 30 cm/sec, using the chart of Sunborg (1956, quoted in Lauff 1967). Currents were probably responsible for winnowing much of the clay from the sands. During deposition of the carbonaceous shales, currents were slight, because anaerobic conditions could only be maintained with minimal circulation.

Dickins (1963) believes that *Oriocrassatella* sp. favoured a silt-free environment. Apart from this, however, no evidence is available concerning water turbulence.

(c) Biota: Conditions favourable for abundant organisms were not present during deposition of the lower part of the formation, although some broken shell material is believed to have been present on deposition, and subsequently destroyed by pressure solution.

During deposition of the *Edmondia* band, conditions were favourable for the deposition of "shell banks", as Dickins (1963) believes this was the life habit of *Oriocrassatella*. The growth of shell banks indicates a favourable combination of salinity, temperature, substrate, etc. Conditions were also favourable, during deposition of the *Edmondia* band for boring organisms.

The reason why abundant brachiopods and bryozoans are not present in the Billidee Formation is not clear, but Dickins (1963) states, without reasons, that abundant brachiopods and bryozoans are almost never found together with the molluscan association present in the formation.

The close association of probable root casts and marine fossils indicates that the plants may have been halophytes, possibly filling the same ecological niche (shallow brackish-marine water with some subaerial exposure) as modern mangroves.

Abundant pebbles, up to 14 cm in diameter, are scattered randomly throughout the *Edmondia* band, in fine- to medium-grained calcite-cemented sandstones. The scattered distribution of these pebbles cannot be explained by "normal" sedimentation, and probably burrowing organisms were responsible for reworking coarse-grained beds and distributing the pebbles evenly throughout the member. This same process may also have been responsible for destroying primary lamination, as outlined by Ginsburg (1957).

(d) Regional Controls on Sedimentation: The heavy mineral assemblage suggests that the provenance of the sandstone is similar to that of the Moogooloo Sandstone—that is, from granitic or high-grade metamorphic rocks.

The strong south to north current trend suggests a strong palaeoslope towards the north. The lack of slump structures, however, indicates that the surface of deposition was essentially flat.

The formation thickens towards the north. The significance of thickening down the apparent palaeoslope (i.e. to the north) is not known, and a regional study of the Billidee Formation would be necessary to produce any meaningful conclusions.

Slow subsidence during deposition may have been necessary to produce the thickness of sediments present in the formation.

(e) Substrate: During deposition of the *Edmondia* band, the substrate must have been soft, because Dickins (1963) believes that *Edmondia* sp. was a burrowing form. The bottom was also probably soft during deposition of the organic muds.

Lime muds formed in some sheltered areas with low influx of terrigenous debris. The mud may have been partially stabilized by plants.

The wide distribution of shale clasts, together with the scattered distribution of burrowing bivalves (obviously resulting from transport), indicates that the substrate was actively eroded by currents.

(f) Salinity: Ladd *et al.* (1957) have described deposition of gypsum in organic muds in salinities as low as 9‰. Thus, high salinities cannot be inferred from the abundant gypsum in the shales. Hypersaline conditions may have been necessary, however, for the deposition of gypsum interbedded with orthoquartzite.

(g) Climate: Palynological evidence indicates that the climate was cool, and that no significant climatic change occurred between Callytharra and Billidee time.

(h) Oxygen Supply: The carbonaceous shales were developed in anaerobic conditions (Pettijohn 1957, p. 363). Pyrite indicates local reducing conditions. This pyrite could have been formed within the mud, as outlined by Van Straaten (1951).

In summary, the environment of deposition of the Billidee Formation was shallow water (with some subaerial exposure), fairly strong, essentially unidirectional currents during the deposition of the sandstone, with stagnant anaerobic conditions during the deposition of carbonaceous shale. There was fairly rapid fluctuation between aerobic and anaerobic conditions. The deposition of the *Edmondia* band was marked by a minor marine transgression. The substrate was soft during deposition of the *Edmondia* band. Burrowing bivalves were common, as were *Oriocrassatella* sp. "shell banks".

Comparison of the Billidee Formation with likely modern analogues shows that deposition was probably in an environment similar to the lagoonal bays of central Texas (U.S.A.), described by Shepard and Moore (1955) and by Ladd *et al.* (1957). The bays are separated from the ocean by a string of barrier islands. In these bays are found all of the facies present in the Billidee Formation, arranged in a similar pattern, with rapid interfingering of sands and shales. The bays cover a large area (210 × 24 km). Three distinct facies are outlined by Shepard and Moore. These facies are (moving inland): the beach facies, the bay facies and the marsh-river facies. The majority of the Billidee Formation is believed to represent the bay facies. The *Edmondia* band is thought to represent the beach and lower bay facies, these facies having migrated over the underlying bay facies as a result of a slight transgression.

The conditions and facies present in one of these bays (Hynes Bay) are believed to be closely analogous to conditions and facies in Billidee time, and are quoted in part (from Ladd *et al.* 1967, p. 619, 620):

"Hynes Bay measures 5 by 2½ miles and has a maximum water depth of 4 feet ... A sample of the bottom mud dried to a very dark slightly waxy clay with scattered bits of shell and some sand grains ... averaging 0.25 mm in maximum diameter ... also ... plates of gypsum (selenite) averaging 0.5 mm in diameter ... A rich concentrate of Foraminifera shells ... together with some pelecypods were recovered from the bottom. In areas ... the bottom was clean hard sand under 2 feet of water. One fairly large *Rangia* was the only living mollusk recovered. The sand was fine grained but poorly sorted, consisting largely of grains of glassy quartz up to 0.25 mm in maximum diameter ... together with the shells of smaller foraminifers, ostracodes and worn fragments of mollusks ..."

Salinities of 9‰ are the highest reported from Hynes Bay. This is apparently high enough for the deposition of gypsum. Wood fragments are common in the sand lithofacies. Small streams drain into the bays, supplying detrital material for the sand bodies.

Oyster and mussel bioherms are developed in the lower-bay facies. The typical form of these bioherms is a low mound. Many of the larger bivalves and gastropods are bored. The bioherms are believed to correspond to the *Oriocrassatella* sp. "shell banks" in the *Edmondia* band.

The dominant palaeocurrent direction, from south to north, is interpreted as resulting from periodic currents initiated by streams entering the enclosed bays. The thickening of the formation away from the streams (i.e. towards the north) could have been caused by influx of sand from (or over) the barrier islands and into the enclosed bays. This type of sedimentation has been described by Van Straaten (1951, cited in Lauff 1967) from the Ems estuary.

Condon (1967) believes that the deposition of the Billidee Formation followed a marked change in environment from that of the Moogooloo Sandstone. In the area mapped, however, the contact is gradational, with gypseous carbonaceous shale present in both formations. The upper Moogooloo Sandstone is believed to represent a lagoonal environment similar to the environment of deposition of the Billidee Formation.

Condon (1967, p. 98) also states "The siltstone members of the Billidee Formation were deposited in moderately deep water (perhaps 50 fathoms or more) whereas the arenaceous members were deposited in shallow water (indicated by invertebrate trails and burrows, and ripple marks) ..." He goes on to postulate rapid fluctuation of relative sea level, produced in part by tectonic movement and partially by eustatic sea level changes.

The arguments in favour of a shallow water origin for the shale (and siltstone) units of the formation are:

(a) the shale units are laterally impersistent, a feature that would not be expected from shales deposited in water over 90 m deep. Such shales would be expected to outcrop in traceable beds, over large strike distances, as outlined by Rich (1951).

(b) near the Moogooloo-Billidee contact, thin shale beds are interbedded with lenses of orthoquartzite, containing the shallow water trace fossil *Palaeophycus* sp. The rapid alternation between shale and shallow water orthoquartzite indicates shallow water conditions.

(c) the palynological assemblage (almost complete lack of microplankton) indicates a near-shore, probably shallow water, origin for the shales.

Thus it seems that the shales and the sandstones are all part of a shallow water sequence, and no relative change in sea level is necessary to explain the facies present.

There is no evidence to support Condon's (1967) idea that the depositional surface had high topographical relief, thus influencing sedimentation in Billidee time. The lack of slump structures in the area mapped indicates that the surface of deposition was fairly flat.

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